Removal of Heavy Metal Pollutants (Copper, Chromium and Lead) by a Bi-Phasic Rain Garden Ecosystem

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Abstract

Rain gardens are a relatively new best management practice (BMP) to treat urban stormwater runoff while additionally providing for an aesthetically pleasing landscape. The runoff, diverted from the storm sewer, is treated in the rain garden before recharging the groundwater. Heavy metals in urban areas are a concern due to both their persistence in the environment and potentially adverse health effects. Three replicated rain gardens were constructed using a novel bi-phasic design that consists of both an anaerobic (oxygen-deprived) and an aerobic (oxygen-rich) zone. A field study was conducted whereby multiple rainfall events were applied to collect simulated stormwater runoff from a concrete pad. During each simulated rain, water samples were collected at three sampling points: 1) the inlet to the rain garden, 2) the interface between the anaerobic and aerobic zone, and 3) at the final discharge of the aerobic zone. The water samples were analyzed for copper (Cu), chromium (Cr) and lead (Pb) to determine removal efficiency. Initial concentrations of the metals in the water entering the rain gardens were in excess of the legally enforceable Environmental Protection Agency's (EPA) Maximum Contamination Level standards (MCL) by at least 7.5 times. The rain gardens were effective in removing metals with results showing a decrease in the heavy metal concentrations at both sampling points 2 and 3; overall, the removal was a greater than 99%. Of the 36 samples analyzed from the aerobic (final) discharge pipe, all were also below the MCL.

Introduction

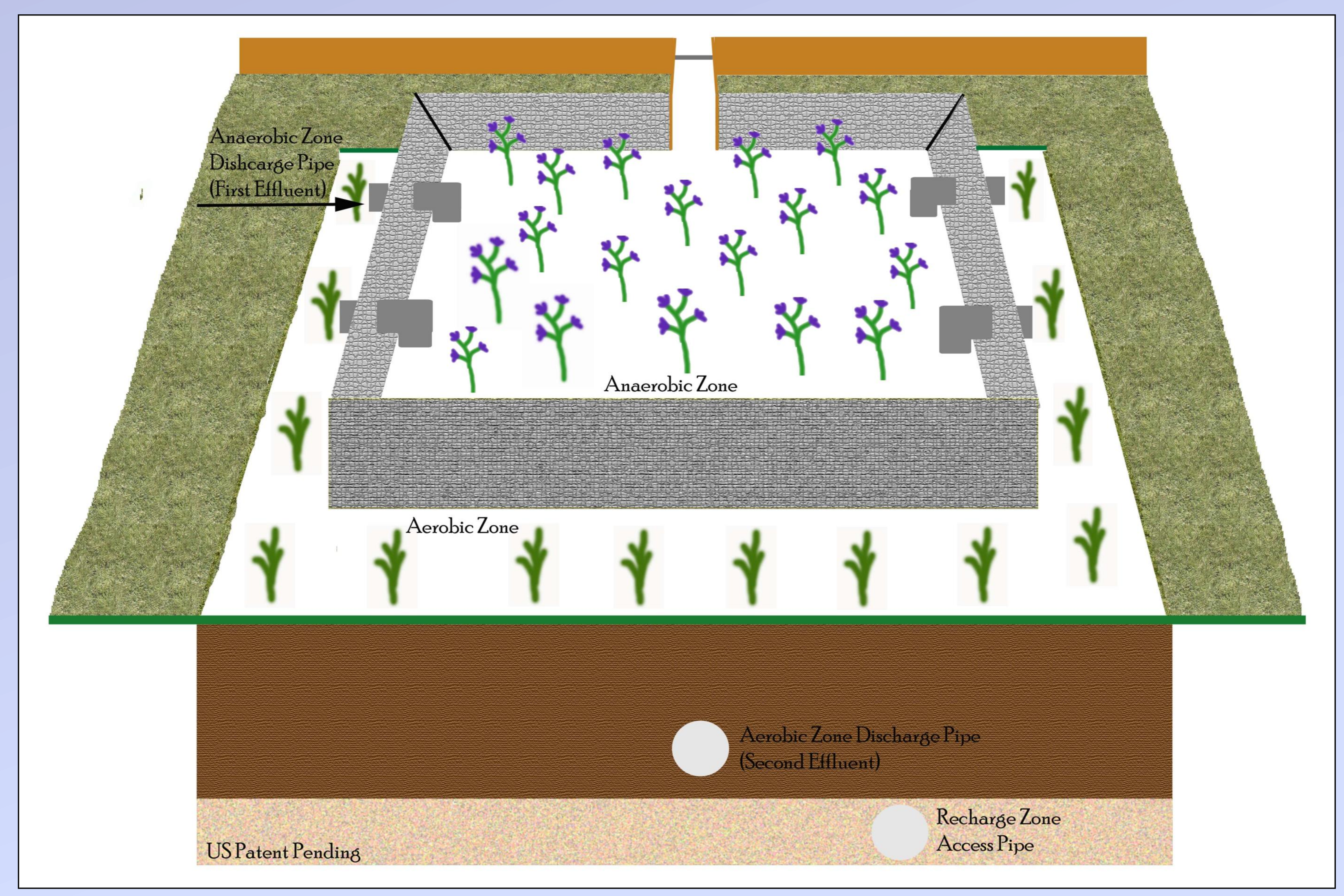
As water moves through a watershed, it collects and transports the pollutants present. In urban areas, impervious surfaces are one of the leading sources of pollution of surface waters and can also contaminate groundwater. Large areas devoted to roadways, parking lots, buildings and sidewalks create the need to manage the water that results from storms. As people continue to migrate into urban areas, concerns regarding the effect of impervious areas on the environment will continue to increase.

Rain gardens are a specific type of bioretention system and are a relatively new best management practice (BMP) approach to treat stormwater runoff while providing an aesthetically pleasing landscape. The main components include: a ponding area, a mulch layer, a soil layer, a gravel layer and, optionally, an under-drain. Plants, often species native to the area, promote evapotranspiration, biological activity, pollutant uptake and help maintain efficient infiltration.

Table 1: Summary of heavy metal concentrations, dates of application and associated runoff volume. Note that no pollutants were applied on day 11. EPA MCL standards are also indicated.

			Chemical pollutant, mg/L		
Timeline	Simulated rainfall event	Runoff volume (L)	Cu	Cr	Pb
Day 1	0.5 in (1.27 cm) for 1 hr	880	10.0	5.0	5.0
Day 6	0.5 in (1.27 cm) for 1 hr	880	10.0	5.0	5.0
Day 11	6.5 in (10.01 cm) for 24 hrs	11,500	-	-	-
EPA MCL Standards		-	1.3	0.1	0.015

The three replicated rain gardens used for the experiment in Wooster, Ohio.



Bi-Phasic Rain Garden design showing the anaerobic and aerobic zones. Water from the anaerobic zone can only enter the first effluent pipes from the bottom of the zone. The aerobic discharge pipe is also at the bottom of the zone.

Left: Heavy metal pollutants upon entering the rain garden. Center: Ponding in the anaerobic zone. Right: Tipping Bucket used to calculate the water flow out of the system at the final discharge (from the aerobic zone).

Materials & Methods

• This study is part of a larger experiment described by Yang et al. (2009, in press). Construction began in the fall of 2007 and was completed the follow spring at the Ohio Agricultural Research and Development Center (OARDC) in Wooster, Ohio. Each of the three rain gardens consist of an inner anaerobic (oxygen poor) zone and outer aerobic (oxygen rich) zone. The soil media, which is a mixture of 60% sand, 20% compost and 20% topsoil, is designed for a 1-hour storm with a 10-year return frequency. In May of 2008, seedlings of six plant species native to Ohio were introduced. A layer of mulch, approximately 3 cm, thick was added in June.

• The experiment was carried out over 12 days under multiple-rainfall conditions (Table 1).

Results

• Effluent water samples were collected on day 11 only. Influent concentrations are based on solutions applied for the two days.

• Results are in Table 2.

	Rain Garden	Cu (mg/L)	Pb (mg/L)	Cr (mg/L)
Influent	In each	20.0*	10.0*	10.0*
First Effluent	1	0.4411	0.0092	0.0581
	2	0.0400	0.0000	0.0158
	3	0.1507	0.0227*	0.0000
Second Effluent	1	0.0095	0.0000	0.0125
	2	0.0116	0.0000	0.0089
	3	0.0661	0.0112	0.0000

Table 2: Heavy Metal Data for each rain garden. An asterisks (*) indicates the value is in excess of the EPA's MCL standards.

Discussion & Conclusions

• This is the first study to utilize a high input level of pollutants. Previous studies focused on remediation of on-site pollutants, which were at levels below the EPA's MCL.

• Each rain garden was capable of reducing the heavy metal pollutants to below regulatory levels. Overall, the anaerobic and aerobic zones reduced the concentration of heavy metals by greater than 99%.

• Further studies into the long-term capabilities of the rain gardens to remediate heavy metals would aid in determining their capacity and potential lifespan. Techniques to not only retain the heavy metals, but also accumulate them in ways that could be easily removed and then properly disposed would increase the lifespan of the rain garden. Possible avenues of investigation include using plants that accumulate heavy metals or using specially designed removable filters that bind and immobilize the heavy metals.

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